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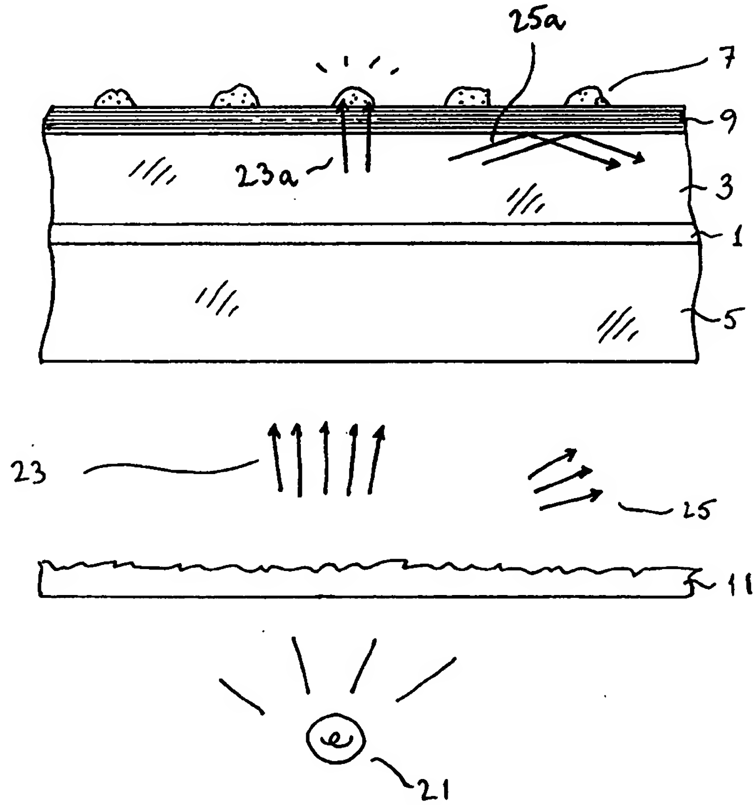
(54) Title: DISPLAY WITH A DIELECTRIC STACK FILTER

(57) Abstract

A display has a modulator, preferably a liquid–crystal cell, adapted to modulate activating UV light (23, 25) input from the rear of the cell on to phosphor–type output elements (7) at the viewer side of the cell, and a pre–collimating device (11) such as a prismatic sheet for partially collimating the input light before it reaches the cell, in order to improve the contrast of the liquid–crystal modulator. In the invention a further collimator is included in the form of a dielectric stack filter (9) between the cell (1) and the output elements (7). This filter is tuned to block the essentially monochromatic input light (25a) emerging from the cell at angles greater than a predetermined angle to the normal to the cell, and also acts to block the passage of light at visible wavelengths. This ensures a good light throughput while eliminating the most harmful (i.e. contrast–degrading) off–axis rays.



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DISPLAY WITH A DIELECTRIC STACK FILTER

The present invention relates to liquid-crystal displays, and in particular, though not exclusively, to photoluminescent liquid-crystal displays (PLLCDs). In such displays, as described for instance in Fig. 3 of GB-A-2154355 (Ricoh Co.) phosphor dots are placed on top of a liquid-crystal cell, and ultra-violet excitation light is input from the rear. The liquid-crystal layer modulates the ultra-violet light and this modulated ultra-violet light then hits the phosphor dots, causing them to luminesce. In such displays, in the absence of any collimation of the UV excitation light the phosphor effectively integrates the entire contrast performance of the electro-optic device over the range of input angles, which is not ideal since for most liquid crystals the contrast ratio is low at some angles.

In order to improve the observed contrast of PLLCD devices, several methods have been proposed concerning collimation of the excitation light from the diffuse backlight (before the light falls upon the liquid crystal layer) - see for instance WO 95/27920 (Crossland et al.). In whatever form, this collimation, approximate though it usually is, results in much of the excitation light being directed through the liquid-crystal cell in a direction offering preferentially high contrast. The collimation therefore provides a means for improving the contrast of the display, whilst also improving the achievable resolution by reducing the cross-talk between adjacent phosphor pixels.

Although directional backlighting is particularly useful for photoluminescent LCDs it has applications also for certain conventional displays. For instance,

some displays, such as bank teller machines, benefit from a narrow field of view of the display because it offers better security. Moreover even a conventional LCD intended to have a wide angle of view can use collimated backlighting if there is a diffuser plate on the viewer side for spreading the light once the image is formed.

One method for the collimation of diffuse narrow-band light into a narrow angular cone is that described in the applicant's earlier PCT patent application No. PCT/GB98/01203. This relies on the angular transmission characteristic of an optimised dielectric-stack filter. Here, the diffuse narrow-band UVA light to the rear of the cell is permitted to pass through the filter in (primarily) the forward direction, but is rejected (reflected) if incident at angles greater than a certain angle away from the normal. The reflected light can be given further chances to pass through the filter (within the narrow angular transmission range of the filter) following reflections from a diffuse reflecting surface situated behind the dielectric stack.

Another method commonly used for collimating diffuse light within conventional liquid-crystal displays (and also applicable to PLLCDs) involves refraction of the light using optical films, such as 3M's Brightness Enhancement Film (two crossed layers of such a film being the preferred option). Such films have been found to direct much of the diffuse light in the forward direction, but only to within a cone having a rather large half-angle, and with considerable amounts of stray light emerging at angles greater than about 40 degrees from the normal (see Figure 1). This stray light, in particular in the case of PLLCDs, is undesirable, since it is likely to give rise to a poor contrast ratio in the switched liquid crystal and will

contribute to (and consequently reduce) the overall contrast of the display.

To achieve the aim of improving contrast and resolution of backlit and photoluminescent LCDs using such types of collimation, it is necessary to cut out the excitation light emerging from the liquid crystal at angles significantly away from the normal, without losing so much of the light input that the display is too dim.

The present invention in one aspect provides a display having a modulator, preferably a liquid-crystal panel, adapted to modulate light input from the rear, and a pre-collimating device for partially collimating the input light along an axis before it reaches the modulator; the display further including a filter, preferably a dielectric stack, on the output side. The filter can be adapted to block input light emerging from the modulator at angles greater than a predetermined angle to the axis; if the display uses output phosphors activated by input UV light then the filter can also prevent UV light scattered by (rather than causing activation of) the phosphor from re-entering the modulator at an acute angle, which would be undesirable.

The invention allows the use of an imperfect or partial collimator at the rear of the modulator, increasing brightness by ensuring that most of the diffuse light from the source is thrown forwardly, while the filter eliminates the smaller portion of the light that is significantly away from the normal. An advantage of using such a two-stage collimator is that, when emissive output elements such as phosphors are used, in combination with UV or near-UV activation light, the second collimation element (i.e. the dielectric stack filter) can be positioned almost adjacent to the emissive layer at the front of the

display thus permitting only the activating light that remains collimated after traversing the display to strike the emissive layer. Activating light that is scattered by various components within the display may no longer be travelling in a preferred direction and may no longer possess the desired polarisation. Such scattered light (which will most likely have been poorly modulated by the liquid crystal and will be approaching the emissive layer at high angles) will be rejected by the second collimation stage. If such light were allowed to strike the emissive layer, reduced contrast and increased cross-talk would result, leading to a reduction in overall display performance.

Preferably the filter is a dielectric filter in the form of a stack, and it can be broadly similar in design to that described in patent application No. PCT/GB98/01203, being made for instance of multiple pairs of layers of differing refractive index. However, in the present invention the stack is situated in front of the liquid-crystal cell or at least in front (on the viewer side) of the liquid-crystal layer itself, and as close as possible to the underside of the visible-emitting phosphors, or other display output elements, of the PLLCD. It can be on the front plate (on the analyser if present) of the LCD or on a separate substrate; in the latter case the phosphors would also be on an auxiliary substrate, possibly the same as the filter substrate.

The filter acts as an angular discriminator, rejecting any of the narrow-band excitation light incident at angles considerably off axis, and it should reflect the entire visible range at normal incidence. Furthermore, the filter will also reflect a considerable amount of the activating UV light that is back-scattered from the visible-emitting phosphor layer back towards the phosphors rather than allowing it to pass

back into the display. This UV light will then have another chance to activate the phosphors. Methods of designing such stacks for particular requirements are known.

The pre-collimating device may be a relatively crude optical lens-type array, such as the BEF film as supplied by 3M, or it may itself be a dielectric stack filter. Alternatively light could be directed forwards in one dimension by using a one-dimensional source in a reflecting trough of parabolic section.

When the output elements are of emissive material, such as a phosphor material, another function of the filter in such an arrangement is to reflect most of the visible backward emissions from the front face phosphors. Such a function is mentioned in US-A-4830469 and US-A-4822144 (US Philips). This will lead to enhanced brightness from the display. Furthermore, since for this purpose the filter will ideally be designed to have a reflection band covering the whole of the visible spectrum (at normal incidence) it becomes possible to use this component to filter out the visible lines emitted from the Hg fluorescent backlight. The use of a "Woods glass" visible-absorbing/UVA-pass filter (i.e. for the lamp envelope) in such an arrangement would therefore be unnecessary. For this purpose, the filter can be designed to reflect visible light from the backlight at any wavelengths and angles that are passed by the first collimation stage.

US 4830469 and 4822144 discuss forward reflection of the visible light emitted by the phosphors, but not filtering of the input activating light. In these patents the activating light is from a high-pressure mercury-vapour lamp at about 365 nm. Such a lamp will generally have an envelope of Woods glass to absorb visible radiation. An absorbent filter has a long cut-off "tail", i.e. the cut-off of wavelengths is gradual.

This means that the wavelength of the source must be considerably below the visible to avoid loss of efficiency by way of absorption in the filter. However, the shorter the wavelength used the greater the difficulty in finding compatible materials for the liquid-crystal cell.

According to a second aspect of the invention therefore there is provided a liquid-crystal display including a source of activating light at a predetermined range of wavelengths, a liquid-crystal layer for modulating the activating light, and an output layer emitting at longer wavelengths when struck by activating light that has been passed by the liquid-crystal cell; the display further including a filter between the liquid crystal and the output layer, the filter being composed of a stack of dielectric layers of thicknesses and refractive indices such as substantially to pass all of the said activating light at normal or near-normal incidence, but to reflect such light that is significantly off the normal, say at greater than about 30°.

In an alternative, related, aspect the liquid-crystal display includes a source of activating light at a predetermined range of wavelengths, a liquid-crystal layer for modulating the activating light, and an output layer emitting at longer wavelengths when struck by activating light that has been passed by the liquid-crystal layer; the display further including a filter between the liquid crystal and the output layer, the filter being composed of a stack of dielectric layers, in which the source of activating light also emits in the region of the said longer wavelengths, these wavelengths being stopped by the dielectric filter.

Because the cut-off edge of the filter in terms of wavelength can be set to be only just above the

wavelength of the excitation light (as opposed to US 4830469 where the cut-off edge is not defined but may lie anywhere between the wavelength of the excitation light, at 370 nm, and the visible emissions of the blue phosphors at, say, 450 nm), the stack filter blocks inclined light rays of the activating light, and it will also prevent all wavelengths longer than those of the activating light from reaching the phosphors, and light from the phosphors from passing back through the cell. Because dielectric-stack (interference) filters can be designed to have a very sharp cut-off the wavelength range of the activating light can be very close to the visible range without there being any danger of visible light, in particular blue light, from the phosphors passing back through the filter or of visible emissions from the lamp passing through the system.

Moreover ordinary glass can be used for the envelope of the light source, reducing its cost and reducing unwanted absorption. It is advantageous to have the activating light in the near-visible UV or even in the short-wavelength visible, as described for instance in GB 2291734 (Samsung). Hence in preferred embodiments the activating light has a wavelength in the region 380-405 nm and the filter has a cut-off at a wavelength somewhat longer, by say 10 nm, than the peak. When the standard 365 nm kind of lamp is used the cut-off can be in the region of 375 nm. The cut-off should be below about 405 nm in any event, to cut out the 405 nm mercury line. What is important is to cut off any input radiation at significantly off-normal angles.

A further detail that should be considered is the substrate on which the filter is formed. Since the filter is ideally located directly adjacent to the emissive phosphor layer, between the phosphors and the

activation light modulator, it is important that the substrate be as thin as possible. This is because the phosphor elements will be further displaced from the liquid-crystal layer by the thickness of the filter and associated substrate. The activating light that is switched by the liquid crystal will then have further to travel before striking the phosphors. If the activating light is not perfectly collimated, this additional distance will permit further divergence of the activating light. This spreading will lead to a 'blurring' of the image produced by the phosphor screen. In the worst case, the spreading may lead to 'cross-talk' where a phosphor pixel adjacent to the one being activated is also struck by the UV light and hence will also be activated. The adjacent phosphor pixel may emit a different colour to the chosen pixel and the result will be a de-saturation of the observed colour.

To minimise this problem, it is advantageous to form the filter on as thin a substrate as possible, such as the emerging range of 'micro-sheet' thin glasses which can have thicknesses in the range of less than 100 microns. Alternatively, thin plastic substrates could be used such as thin films of polyester, PMMA, polycarbonate, tri-acetate cellulose or others. To deposit dielectric filters on such substrates, it is unlikely that electron beam evaporation techniques could be used, because of the high processing temperatures required to achieve high quality optical performance. Hence it would be necessary to use a more recent technique such as that used by OCLI, where low-temperature sputtering of the pre-cursor films is performed followed by an oxidation step to form the dielectric oxide layers. This method allows high-quality filters to be deposited on thin substrates that have low temperature capability. To

reduce the thickness of the component further, the filter could be deposited directly onto one of the existing components in the display such as the polariser, hence avoiding an additional substrate. While generally a large number of dielectric layers in the filter leads to preferred performance, the benefits can still outweigh the losses using fewer than 20 layers. Such simple filters are particularly well suited to the low-temperature sputtering process described above.

For a better understanding of the invention embodiments of it will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a diagram of the characteristics of known pre-collimation layers, as already discussed;

Figs. 2 and 3 show the filter characteristics of interference filters at various angles of incidence, useable with the invention;

Fig. 4 schematically illustrates a display using the invention; and

Fig. 5 shows the various light paths within a display device in accordance with the invention.

In the device shown in Fig. 4 a display panel is constituted by a liquid-crystal layer 1 not shown in further detail sandwiched between glass substrates 3, 5 to form a light-modulating cell. Since the liquid-crystal material is to work with ultraviolet light it should have a low UV absorption, e.g. the Merck material ZLI2293 in a thin cell. The cell thickness d and birefringence Δn are preferably matched to the first or second Gooch Terry minimum; typically d is 1.5 to 6μm. For ZLI2293 the first and second minima are at 2.11μm and 4.71μm respectively at a UV wavelength of

365nm (2.23μm and 4.97μm at 385nm). Such a cell is formed in its twisted construction (for example, 90° or 270° twist) between two polarisers, or after one polariser if a dichroic dye is incorporated into the liquid-crystal material. x, y electrodes (not shown) are provided in the usual way on the cell walls so as to form a matrix of addressable pixels.

Phosphor dots 7 are located in this embodiment on the front (viewer) side of the front glass plate of the cell in an RGB matrix corresponding to the pixels of the cell, as described in WO 95/27920. The phosphors can be, for instance, those disclosed in US-A-3669897 (Wachtel). The front plate further includes a filter layer in the form of a dielectric stack 9 on the front glass 3. For standard twist-cell configurations a polarizer will also be included, deposited on the front glass 3 underneath the stack 9; if it is considered undesirable to deposit an inorganic interference filter on a polariser made of organic material, the stack can instead be applied as a separate layer on its own substrate with the phosphors. A light source 21 is located behind the cell and emits near-UV activating light at 385 nm, among other wavelengths. This light is partially collimated along the optic axis, normal to the panel, by a pre-collimator 11, most of the light being diverted to a cone 23 of half-angle about 20° with a smaller side-lobe 25 at around 50°, as shown in Fig. 1.

The dielectric stack 9 is tuned so as to eliminate the side-lobe by reflecting it as shown at 25a after it has passed through the LC cell, while passing the central cone as shown at 23a. In this way a large percentage of the UV light emitted by the lamp 21 is put to use in the display.

Such a dielectric stack, made for instance of alternating layers of Ta_2O_5 and SiO_2 or MgF_2, is

currently commercially available, offered by OCLI as a UV transmission (and visible-blocking) filter; its transmission characteristics against wavelength for various angles of incidence are shown in Figure 2. At normal incidence (thickest curve) UV is passed up to a cut-off (50%) at about 405 nm, little visible light above this wavelength passing through the filter. As the angle of incidence increases the cut-off wavelength becomes progressively shorter. Small modifications of the design can be made to optimise the position of the transmission edge with respect to the UVA phosphor emission characteristic, whilst retaining the broad-band visible reflection. For instance, it would be useful to have the left-hand cut-off (50%) for normal incidence at about 395 nm instead of 405 nm, with activating light at 385 nm ± 10 nm. The characteristics of such a modified filter are shown in Fig. 3, along with an emissive spectrum for the activating light. The peak at 366 nm, and the lesser one at 405 nm, are larger in this experimental measurement setup than they would be in an actual display.

In the present embodiment, a 3M BEF film is used to partially collimate the emissions from the backlight before it passes through the LC cell. The dielectric stack 9 positioned in front of the cell then acts as a multi-purpose component. It rejects stray UVA light 25a incident at high angles, reflects most of the visible (> 420 nm) backward emissions from the RGB phosphors and cuts out virtually all of the visible emissions from the backlight.

In an alternative embodiment, instead of the BEF film the pre-collimator can be in the form of a second dielectric stack in the manner described in PCT/GB 98/01203. Such a stack will have a cut-off wavelength of say 395 nm for activating light at normal

incidence, but it may let through wavelengths longer than this at certain shallow angles. The secondary filter of the invention can then be tuned so as to eliminate the light travelling at these angles.

Using the standard filter design, some leakage of the green Hg lines occurs at high angles of incidence (between about 50 and 80 degrees off axis), as can be seen from Fig. 2. This may be resolved by using a modified design, but in some cases is not necessary if the liquid crystal is able to switch visible light as well as the UVA excitation wavelengths. A small amount of green light from the mercury fluorescent backlight passes through the filter at high angles. This does not significantly alter the saturation of the green phosphor emissions, but shifts the perceived CIE co-ordinates of the red and blue emission. Using a red or blue phosphor with more saturated emission than required can counteract this. The green addition in this case will "pull" the colour toward the desired CIE co-ordinate (e.g. that required for a standard RGB display).

CLAIMS

1. A display having a modulator (1) adapted to modulate light input from the rear, and a pre-collimating device (11) for partially collimating the input light along an axis before it reaches the modulator; the display further including a light filter (9) on the output side of the modulator.

2. A display as claimed in claim 1, in which the filter (9) is adapted to block the passage of light, such as input light emerging from the modulator, at angles greater than a predetermined angle to the axis.

3. A display as claimed in claim 1 or 2, in which the filter (9) includes at least one dielectric stack positioned on the output side of the modulator.

4. A display as claimed in claim 3, wherein the dielectric stack is formed on a thin polymeric or glass substrate less than 1mm thick.

5. A display as claimed in any of claims 1 to 3, wherein one or more of the existing elements of the modulator structure is used as a substrate for the filter.

6. A display as claimed in any preceding claim, in which the modulator is a liquid-crystal device.

7. A display as claimed in claim 6 and further including output elements (7) activated by the input light to produce the viewed display.

8. A display as claimed in claim 7, wherein the filter (9) is situated between the output elements (7) and the activating light modulating layer, preferably immediately adjacent to the output elements.

9. A display according to any of claims 6 to 8, in which the output elements are constituted by photoluminescent materials, such as phosphor materials.

10. A display according to any of claims 6 to 8, in which the output elements are constituted by photochromic materials.

11. A display according to any preceding claim, in which the pre-collimating device includes a refractive collimator.

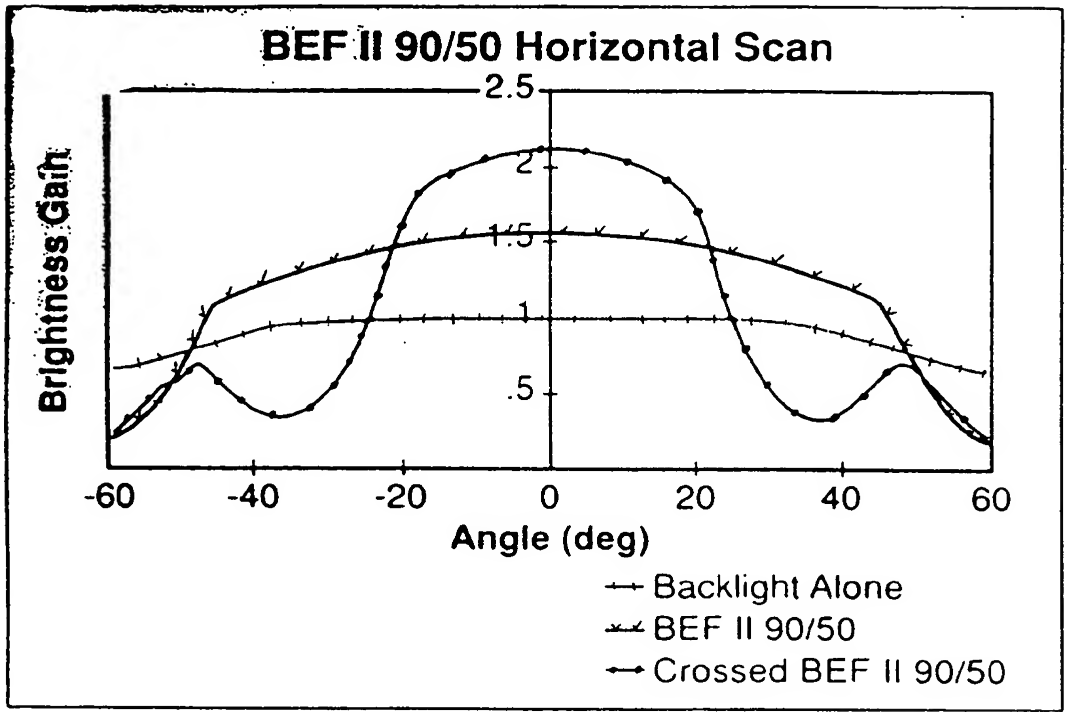
12. A display according to claim 11, in which the collimator is formed by a prismatic sheet.

13. A liquid-crystal display including a source of activating light at a predetermined range of wavelengths, a liquid-crystal layer for modulating the activating light, and an output layer emitting at longer wavelengths when struck by activating light that has been passed by the liquid-crystal cell; the display further including a filter between the liquid crystal and the output layer, the filter being composed of a stack of dielectric layers of thicknesses and refractive indices such as substantially to pass all of the said activating light at normal or near-normal incidence, but to reflect such light that is significantly off the normal.

14. A display according to claim 13, in which the filter blocks the activating light incident at greater than about 30°.

15. A liquid-crystal display including a source of activating light at a predetermined range of wavelengths, a liquid-crystal layer for modulating the activating light, and an output layer emitting at longer wavelengths when struck by activating light that has been passed by the liquid-crystal layer; the display further including a filter between the liquid crystal and the output layer, the filter being composed of a stack of dielectric layers, in which the source of activating light also emits in the region of the said longer wavelengths, these wavelengths being stopped by the dielectric filter.

16. A display according to any of claims 7 to 15, in which the input activation light is substantially monochromatic and has a wavelength in the range 380 - 405 nm.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Brightness Gain
2.5
2
1.5
1
.5
-60
-40
-20
0
20
40
60
Angle (deg)
Backlight Alone
BEF II 90/50
Crossed BEF II 90/50

Fig. 1

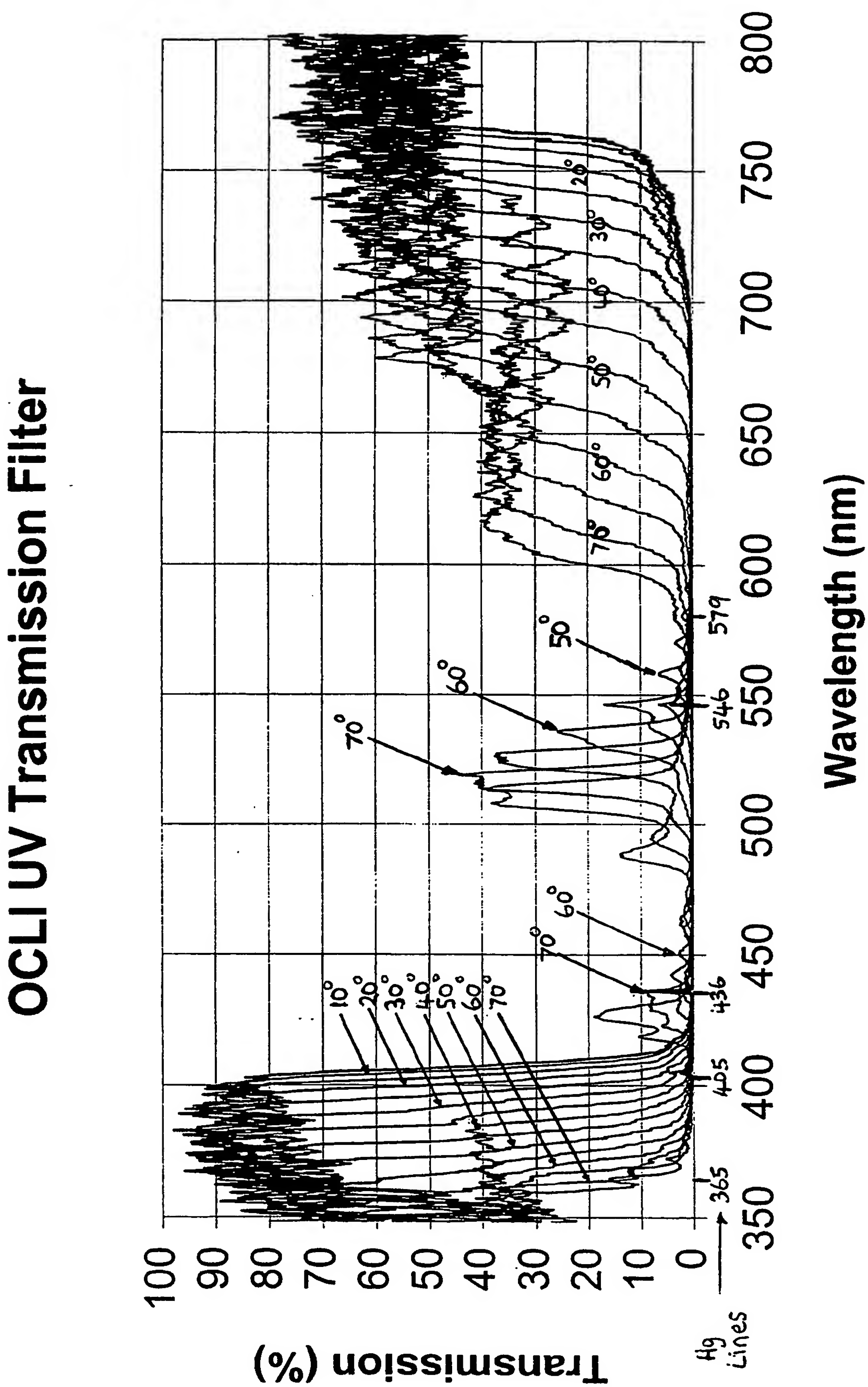
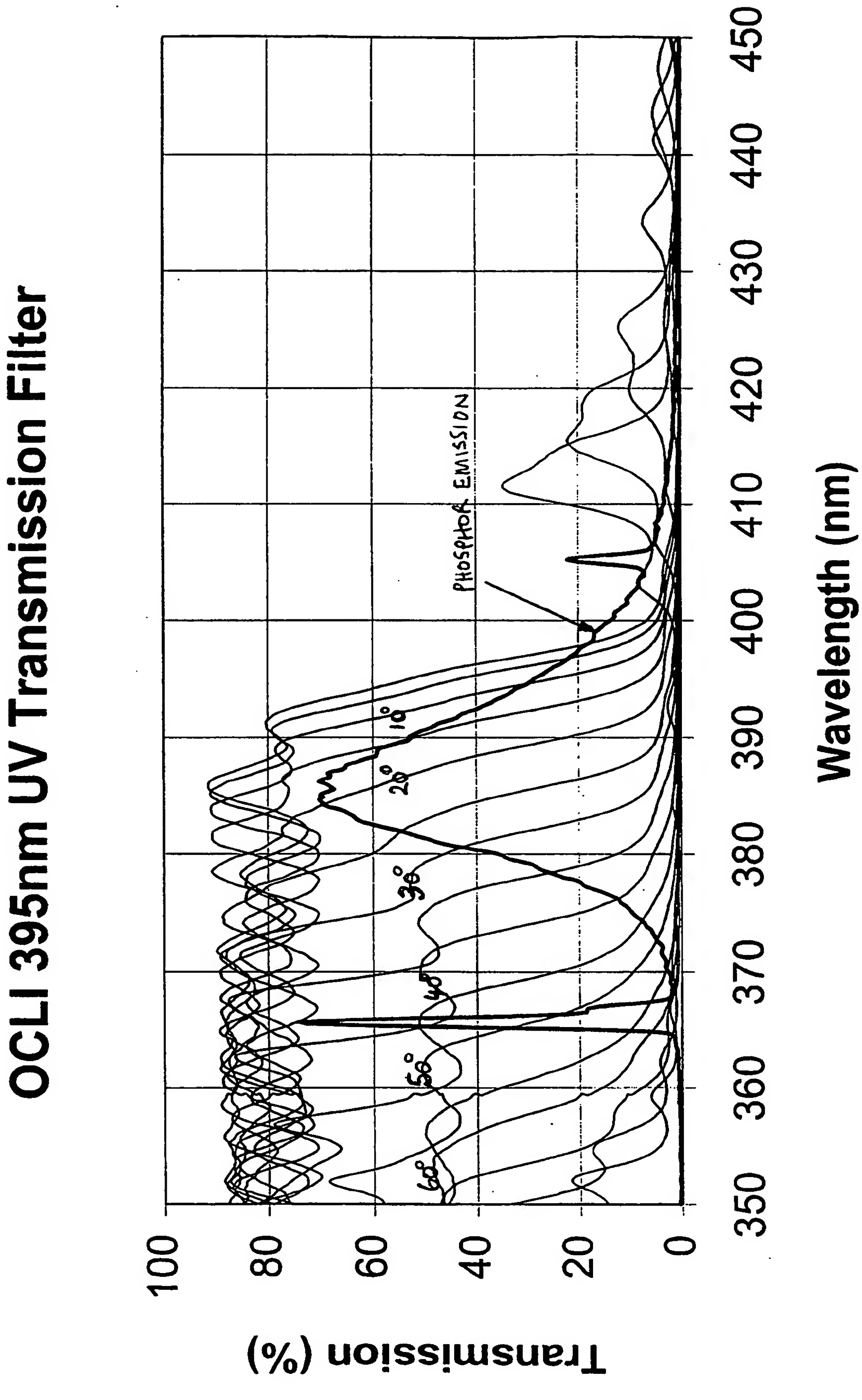

OCLI UV Transmission Filter
Transmission (%)
100
90
80
70
60
50
40
30
20
10
0
Wavelength (nm)
350
400
450
500
550
600
650
700
750
800
Hg Lines
365
405
436
546
579
10°
20°
30°
40°
50°
60°
70°

Fig.2


OCLI 395nm UV Transmission Filter
Transmission (%)
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80
60
40
20
0
350
360
370
380
390
400
410
420
430
440
450
Wavelength (nm)
PHOSPHOR EMISSION
10°
20°
30°
40°
50°
60°

Fig. 3

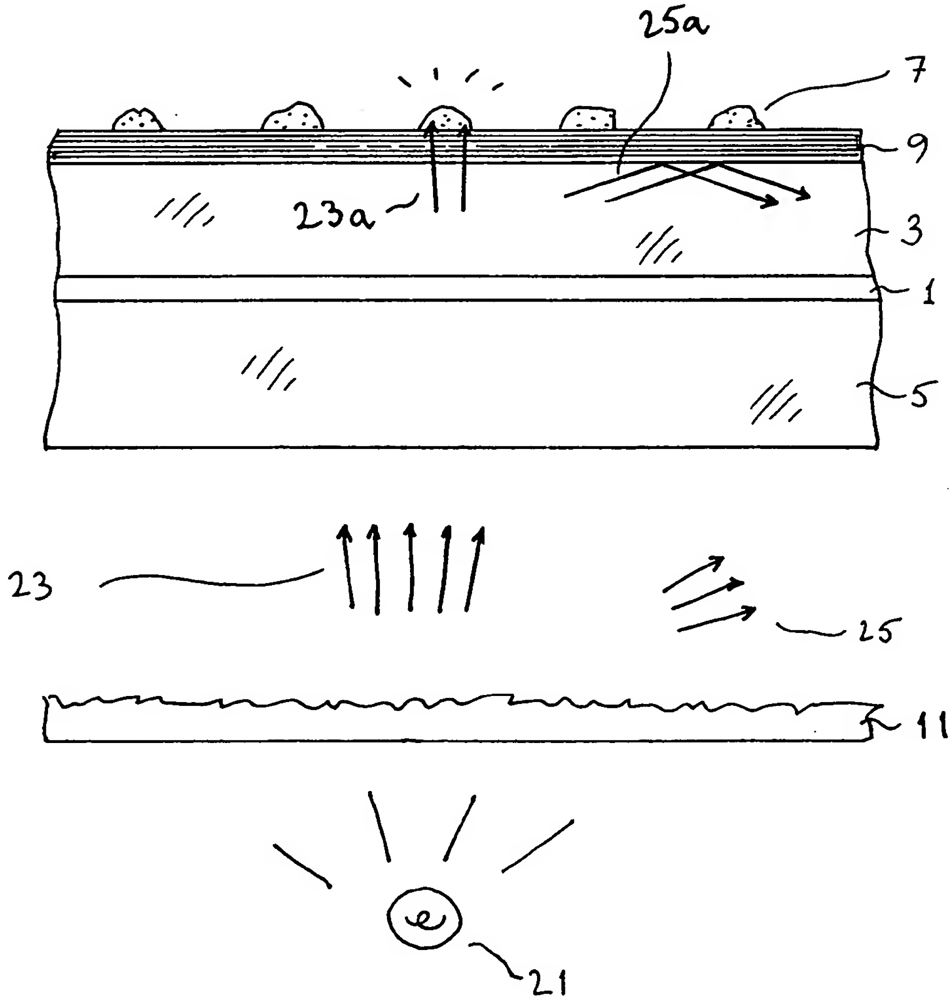

Fig. 4

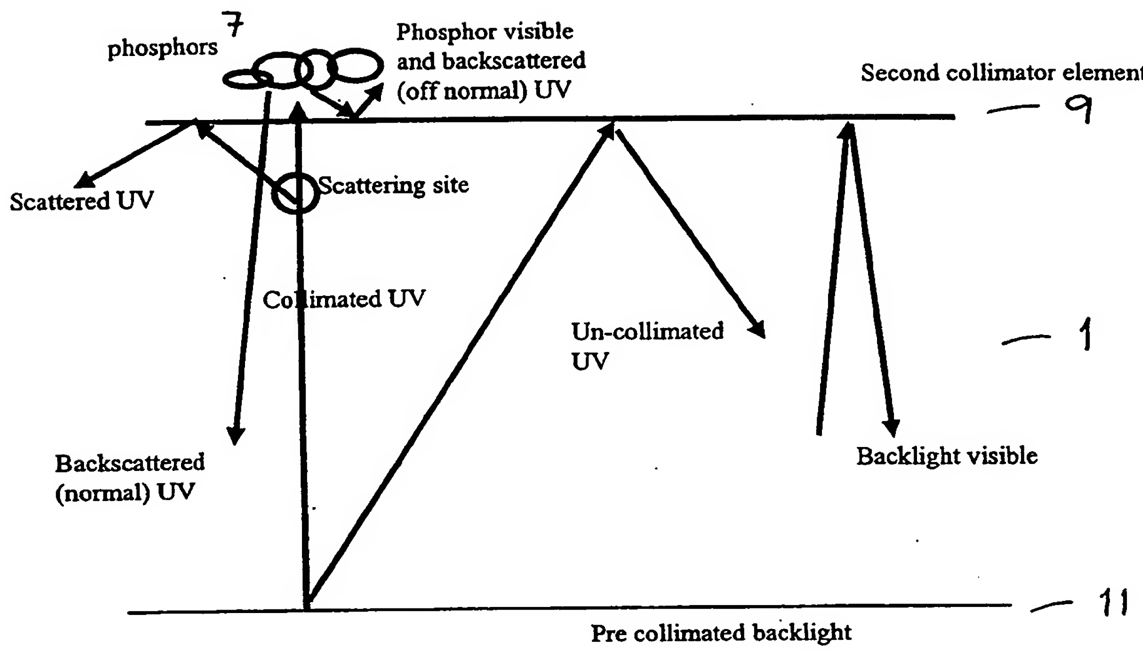
phosphors
7
Phosphor visible
and backscattered
(off normal) UV
Second collimator element
9
Scattered UV
Scattering site
Collimated UV
Un-collimated
UV
1
Backscattered
(normal) UV
Backlight visible
11
Pre collimated backlight

FIG. 5

INTERNATIONAL SEARCH REPORT

Int. ional Application No
PCT/GB 98/02413

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 95 27920 A (CROSSLAND WILLAM ALDEN ;DIXON ALAN COLIN (GB); THOMAS JOHN (GB)) 19 October 1995 see page 12, line 28 - page 13, line 8 see page 15, line 30 - page 16, line 3; figure 7 ---	1-9,11, 12,14,16
Y	CROSSLAND W A ET AL: "33.1: INVITED PAPER: PHOTOLUMINESCENT LCDS (PL-LCDS) USING PHOSPHORS" 1997 SID INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS, BOSTON, MAY 13 - 15, 1997, no. VOL. 28, 13 May 1997, pages 837-840, XP000722821 SOCIETY FOR INFORMATION DISPLAY see the whole document ---	1,16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 November 1998	24/11/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Int ' ional Application No
PCT/GB 98/02413

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 822 144 A (VRIENS LEENDERT) 18 April 1989 cited in the application	13,15
Y	see column 2, line 10 - column 2, line 22	1-9,11, 12,14,16
	see column 3, line 60 - column 5, line 37; figures 2-4	

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